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THE CORIOLIS EFFECT IN ZERO-GRAVITY RESEARCH AIRCRAFT

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## I INTRODUCTION

The purpose of this memorandum is to define and discuss the nature and extent of the Coriolis effect as it exists on board the ASD zero gravity research airplanes during a weightless parabola and to suggest improvements in the pilot's instruments which are used to fly the maneuver.

The ASD zero gravity airplanes have been in use for over four years and during that period considerable time and effort in the form of instrumentation have been expended in an attempt to define the acceleration environment which exists in the free-float area during a weightless maneuver. There appears, however, to have been no attempt to define the effects of Coriolis accelerations which arise because the airplane is rotating in pitch throughout the maneuver.

During early soaring experiments subjects noted that, when pushing off of the aft bulkhead in an attempt to soar the length of the fuselage, they had to aim toward the floor in order not to curve upward and hit the ceiling. Had they been able to soar in the opposite direction (toward the tail) they would have noted a similar tendency to curve toward the floor. Unfortunately, this early experience with curved trajectories was not identified with the Coriolis effect until very recently.

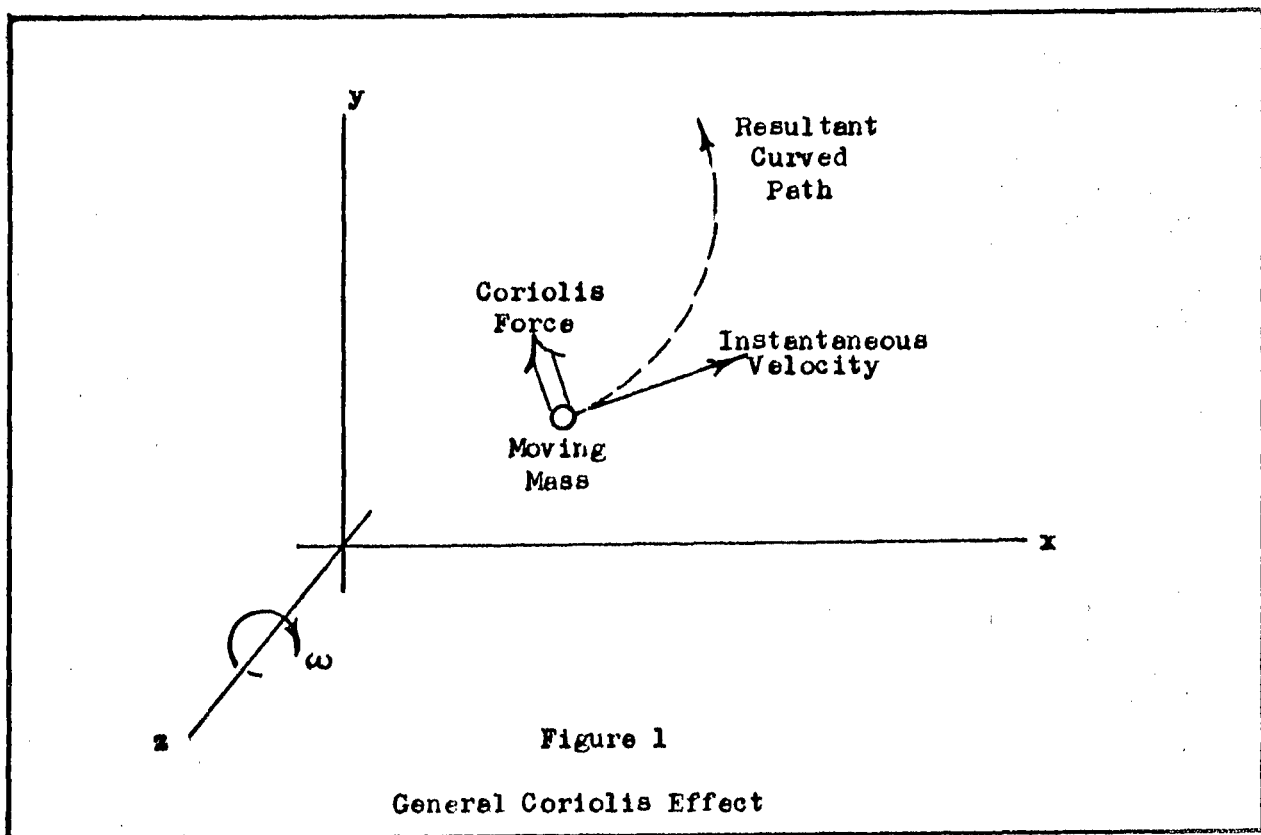
In many zero gravity experiments the Coriolis effect can be ignored, but in others it may contaminate the results sufficiently to invalidate the conclusions. It is hoped that an appreciation of the Coriolis effect will not only help future experimenters in the interpretation of their results, but will also result in improvement of the pilot technique used to fly the weightless maneuver.

## II THE CORIOLIS EFFECT IN THE ZERO-GRAVITY RESEARCH AIRCRAFT

### Coriolis Forces -

Nearly everyone is familiar with Newton's second law of motion which states that force equals mass times acceleration. A fact which is not so universally appreciated, however, is that this law is not valid in a rotating coordinate frame. It is still possible to use Newton's second law in a rotating frame of reference, however, provided only that we introduce a Coriolis force which acts at right angles to the direction of motion of any mass. It is important to recognize that this Coriolis force is not a "true force" in the sense that it does not arise from the electrical or gravitational attraction or repulsion of other matter, but is introduced only in order that Newton's second law may still be used to describe the motion of masses in a rotating reference frame.

To illustrate the Coriolis effect, consider the XYZ coordinate frame shown in figure 1 to be rotating in a clockwise direction with angular velocity,  $\omega$ , in inertial space, about the Z axis.



If the moving mass had an instantaneous velocity in the X-Y plane as shown by the single arrow, it would move as though there were a Coriolis force acting at right angles to its velocity in the direction shown by the double arrow. If there were no external forces acting on the mass it would move in a path curved in a counter-clockwise sense as indicated by the broken line in figure 1. Note that the curvature of the path is always in a sense opposite to the rotation of the coordinate frame.

Only motions in a plane perpendicular to the axis of rotation are affected by Coriolis forces. Referring again to figure 1, any velocity component which the moving mass possessed in the direction of the Z axis would be unaffected by Coriolis accelerations.

#### Aircraft Rotation During Weightless Maneuver -

The interior of the zero gravity aircraft fuselage provides the background against which the motion of a free-floating object is seen. Because the aircraft is pitching nose downward throughout the zero-g portion of the maneuver, this motion is observed relative to a rotating frame of reference and we should expect Coriolis effects to be present.

The rate at which a zero-g aircraft rotates during a maneuver varies with the type of aircraft, entry altitude and airspeed and even varies during the maneuver itself, being a maximum at the apex of the parabola. Experience has shown that the average rotational velocity of the fuselage is about 0.1 radians per second in the C-131 airplane and about 0.05 radians per second in the KC-135 (ref. 1).

The magnitude of the Coriolis force is given by

$$\text{Coriolis force} = 2 m \omega v \quad (1)$$

where  $m$  is the mass of the object traveling with velocity,  $v$ , and  $\omega$  is the angular velocity of the aircraft.

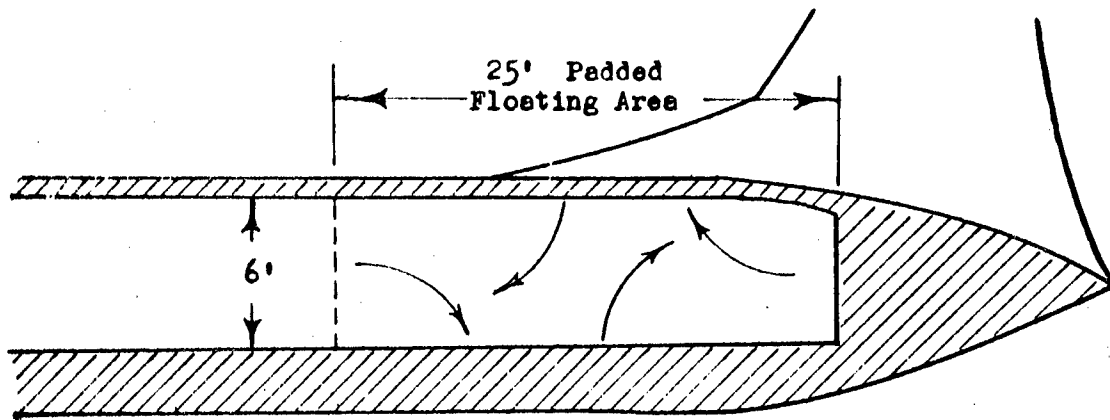
Since the presence of a Coriolis force is due only to rotation of the aircraft and since all portions of the aircraft are rotating at the same rate, the effects will be the same anywhere inside the fuselage. An object's position relative to the center of gravity of the airplane has no effect on the presence or magnitude of the Coriolis forces acting on it.

The axis of rotation of the airplane lies in a direction parallel to the wings, therefore, only fore-aft or up-down motions of a free-floating object will be affected by Coriolis forces: side to side motions inside the airplane will not be affected. Figure 2 illustrates some typical trajectories for a free floating mass traveling at a speed of 1 foot per second in the C-131 airplane.

Under the influence of Coriolis forces any moving object will travel in a circular path. The radius of curvature of the path is given by

$$R = \frac{v}{\omega} \quad (2)$$

where  $R$  is the radius of curvature,  $v$  is the velocity of the moving mass, and  $\omega$  is the angular velocity of the airplane.



**Figure 2**

**Curved Paths Resulting From Coriolis Forces Aboard C-131 Airplane**

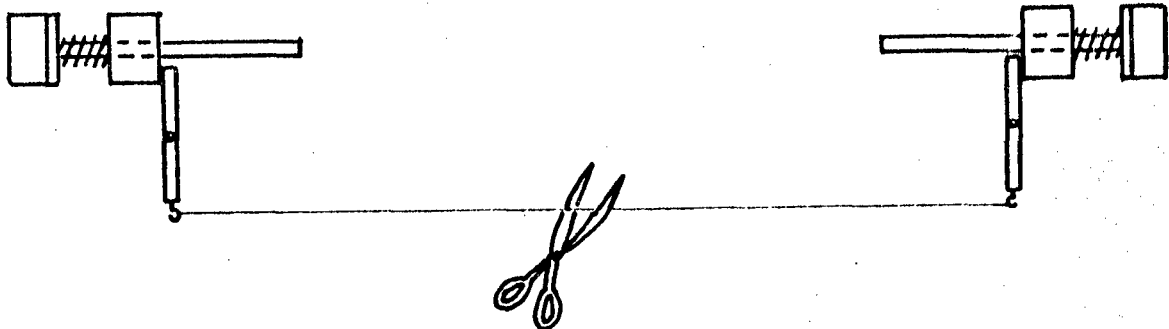
#### Experimental Verification -

The difficulty in detecting Coriolis effects in the zero-g airplanes arises from the fact that it is impossible to fly an absolutely perfect zero-g trajectory. Slight deviations from a perfect flight path will cause a free-floating object to drift erratically within the aircraft. An object propelled in a straight line may curve upward and hit the ceiling or downward and hit the floor. In the past, this curvature has been attributed to imperfect maneuvers. We know now, however, that it can also be due to Coriolis forces which exist during a perfectly flown maneuver.

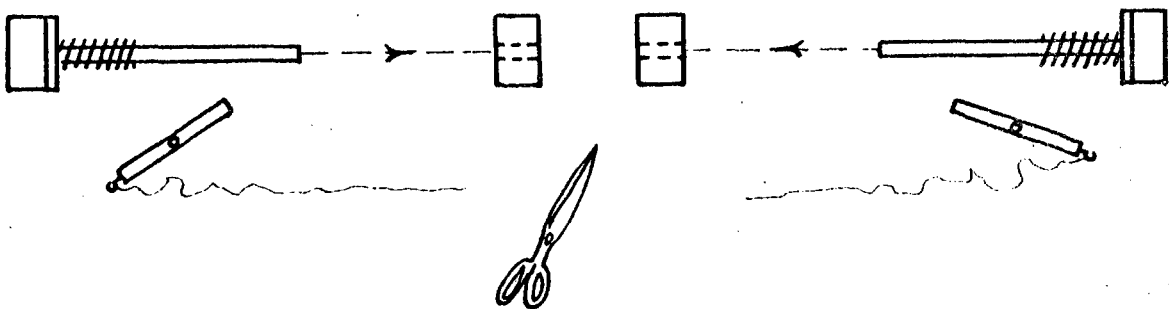
In order to make the Coriolis effect visible in spite of these random vertical and longitudinal accelerations, the device shown in figure 3(a) was constructed. It consisted of two weights which could be triggered simultaneously to fire directly at one another. The weights were guided on metal rods and were propelled by light springs. Triggering was accomplished by burning or cutting the trigger string.

Since both weights leave the ends of their respective guide rods simultaneously, they each become subject to random aircraft accelerations at the same time and will drift up or down together as they approach one another. If there is no Coriolis force present they will collide head on as shown in figure 3(b). If, however, Coriolis forces are present, they will curve in opposite directions and will not collide (figure 3(c)).

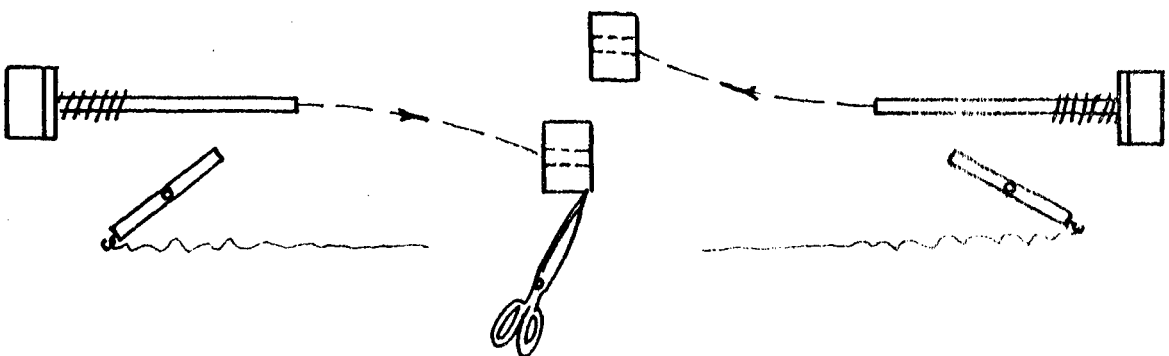
The demonstration device was operated in several different orientations relative to the fuselage and in several different positions relative to the aircraft center of gravity. When the device was oriented longitudinally, the forward-traveling mass always passed over the aft-traveling mass. When oriented vertically, the up-traveling mass always passed aft of the down-traveling mass. When oriented laterally, the masses collided head on. Position relative to the aircraft center of gravity had no effect, as predicted.



(a) Prior to Release



(b) No Coriolis Force



(c) Effect of Coriolis Force

Figure 3

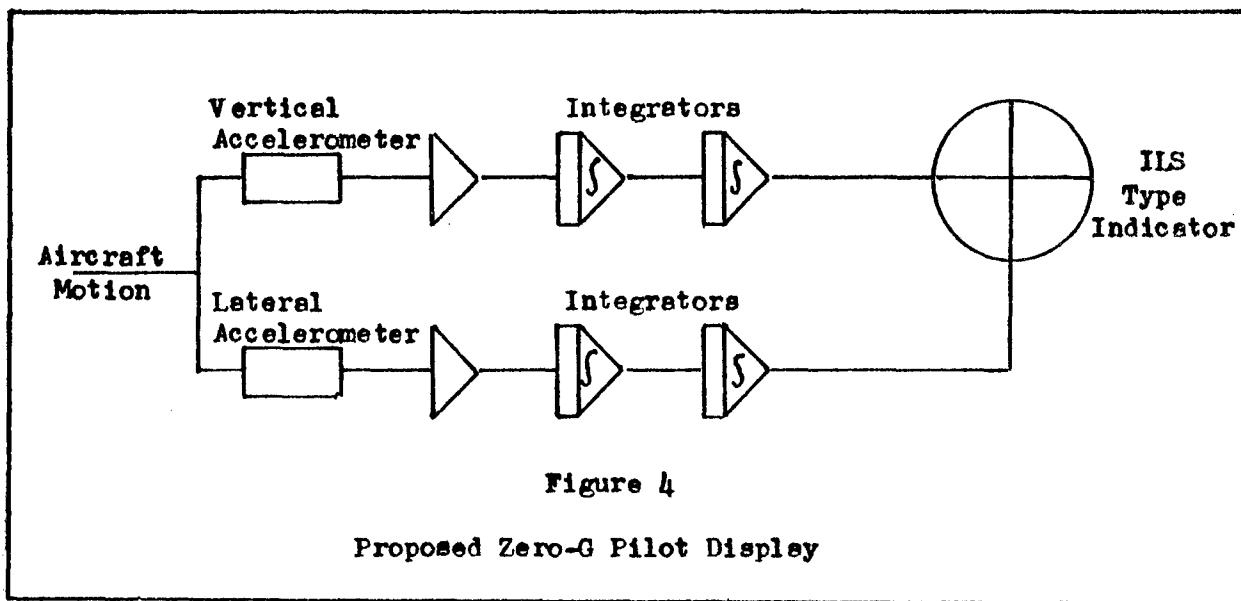
Coriolis Demonstration Device

### III DISCUSSION OF PILOT TECHNIQUE

Many zero-gravity experiments require floating an instrumented package or a man in the aircraft for as long as possible without an impact with the cabin walls, floor, or ceiling. During the impact-free floating time, the package or human subject experiences a perfect zero-gravity state even though the airplane is not flying a perfect maneuver.

In spite of the requirement for maximum impact-free float times, the pilot currently relies on the outputs of bolted down accelerometers, appropriately displayed to him on the instrument panel, in order to fly the maneuver. It would seem that instrumentation should be devised which would enable the pilot to fly the aircraft around a floating package rather than to enable him to zero the readings of bolted down accelerometers. The present instrumentation which is based on presenting acceleration data to the pilot, cannot cope with the problems introduced by Coriolis effects. For example, suppose that after release of a package the co-pilot momentarily deviates from zero longitudinal acceleration. The package will begin to drift forward or aft. Correcting back to zero acceleration will not cause the package to stop drifting and the Coriolis effect will cause it to impact the floor or ceiling even though the pilot and co-pilot maintain zero readings on their accelerometers.

An instrumentation scheme which would enable the pilot to fly around a floating package is shown in figure 4. Instead of displaying acceleration directly to the pilot, the signal is integrated twice and presented as vertical or lateral position of the floating package relative to the aircraft. Vertical and lateral positions are presented to the pilot on an ILS type instrument and longitudinal position is presented to the co-pilot on a single-needle instrument. If integration were started at the instant the package was released, and the pilot kept the needles centered just as if he were flying an ILS approach, the package would float exactly in the center of the cabin. What is more important, however, is that if the package began to drift in any direction, the pilot immediately would have the information necessary to make a correction. Such a system could significantly increase the impact-free float times in zero-g experiments.



#### REFERENCES

1. Hammer, L. R., Aeronautical Systems Division Studies in Weightlessness: 1959-1960, WADD Technical Report 60-715, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, December 1961.

*If want pictures, must put in yourself.*